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EFFECTS OF TURBULENCE INSTABILITIES ON LASER PROPAGATION

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David A. de Wolf

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13. ABSTRACT

Three developments are reported briefly, (a) an extension of average focal-spot areas under turbulent atmospheric conditions to non-zero elevation angles, (b) computation of the temporal power spectrum of angle-of-arrival fluctuations, and (c) development of a new formalism for the irradiance of a plane wave leading to log-normal statistics and promising a saturation effect for the irradiance (not yet computed).

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EFFECTS OF TURBULENCE INSTABILITIES ON LASER PROPAGATION

DAVID A. de WOLF

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INVESTIGATOR: DR. DAVID A. de WOLF
PHONE: 609 452-2700 EXT. 3023

PROJECT ENGINEER: LT. DARRYL P. GREENWOOD
PHONE: 315 330-3443

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FOREWORD

This quarterly report was prepared by RCA Laboratories, Princeton, New Jersey under Contract No. F30602-71-C-0356. It describes work performed from 9 September to 8 December 1971 in the Communications Research Laboratory, Dr. K. H. Powers, Director. The principal investigator and project engineer is Dr. D. A. de Wolf.

The report was submitted by the author on 7 January 1972. Submission of this report does not constitute Air Force approval of the report's findings or conclusions. It is submitted only for the exchange and stimulation of ideas.

PUBLICATION REVIEW

This technical report has been reviewed and is approved.

RADC Project Engineer

ABSTRACT

Three developments are reported briefly, (a) an extension of average focal-spot areas under turbulent atmospheric conditions to non-zero elevation angles, (b) computation of the temporal power spectrum of angle-of-arrival fluctuations, and (c) development of a new formalism for the irradiance of a plane wave leading to log-normal statistics and promising a saturation effect for the irradiance (not yet computed).

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I. PROGRESS DURING THIS QUARTER

The calculation of $\pi < r_L^2 >$, the average focal-spot area, has been extended to slant-path links with the transmitter at an altitude of one meter or so above the ground. We have applied the height dependence of C_n^2 given by Wyngaard, Izumi, and Collins[1]. The results are given by our previous plots of r_{oc} and r_{oL} as a function of L for diverse values of C_n^2 in horizontal propagation, supplemented by plots of $r_{oc}(\theta)/r_{oc}(0)$ for sunny-day and for dawn or dusk conditions. The same plots serve for $r_{Lc}(\theta)/r_{Lc}(0)$ because this ratio is the inverse of $r_{oc}(\theta)/r_{oc}(0)$ at any given elevation angle θ. The plots [Figures 1(a) and (b)] are independent of k (frequency) and C_n^2 (turbulence strength), hence universal.

We have computed the temporal power spectrum $W(\omega)$ of angular fluctuations, i.e., the Fourier transform with respect to τ of $<\delta\theta(t+\tau)\delta\theta(t)>$ averaged over t, for two cases:

(a) Taylor's hypothesis which states that all movement is due to a single velocity v.
(b) A gaussian velocity distribution of independent eddies with zero mean velocity.

In both cases, the spectrum is initially flat, then decreases with $\omega^{-2/3}$ as the angular frequency ω increases above $\omega_1 \approx v/L_o$ up to a cut-off at $\omega \approx \kappa_m L_o \omega_1$. Further work is needed to extend case (b) to a non-zero mean velocity. The results to date are:

<u>Case (a)</u>

$$W(\omega) = W(\omega;5/6) - W(\omega;11/6)$$

$$W(\omega;\rho) = \frac{15.7}{8\pi^{1/2}} \frac{\epsilon^2 L}{L_o \omega_1} \exp -\left(\omega/\omega_1 \kappa_m L_o\right)^2 \times$$

$$\times \left(1 + \omega^2/\omega_1^2\right)^{1/2-\rho} U\left[\frac{1}{2}, \frac{3}{2} - \rho, \left(\omega^2 + \omega_1^2\right)/\left(\omega_1 \kappa_m L_o\right)^2\right]$$

where $\omega_1 = v/L_o$ and U is one of Kummer's functions in the notation of NBS Handbook of Mathematical Functions. The other symbols are defined in the previous quarterly report.

<u>Case (b)</u>

$$W(\omega) = W(\omega;5/6) - W(\omega;11/6)$$

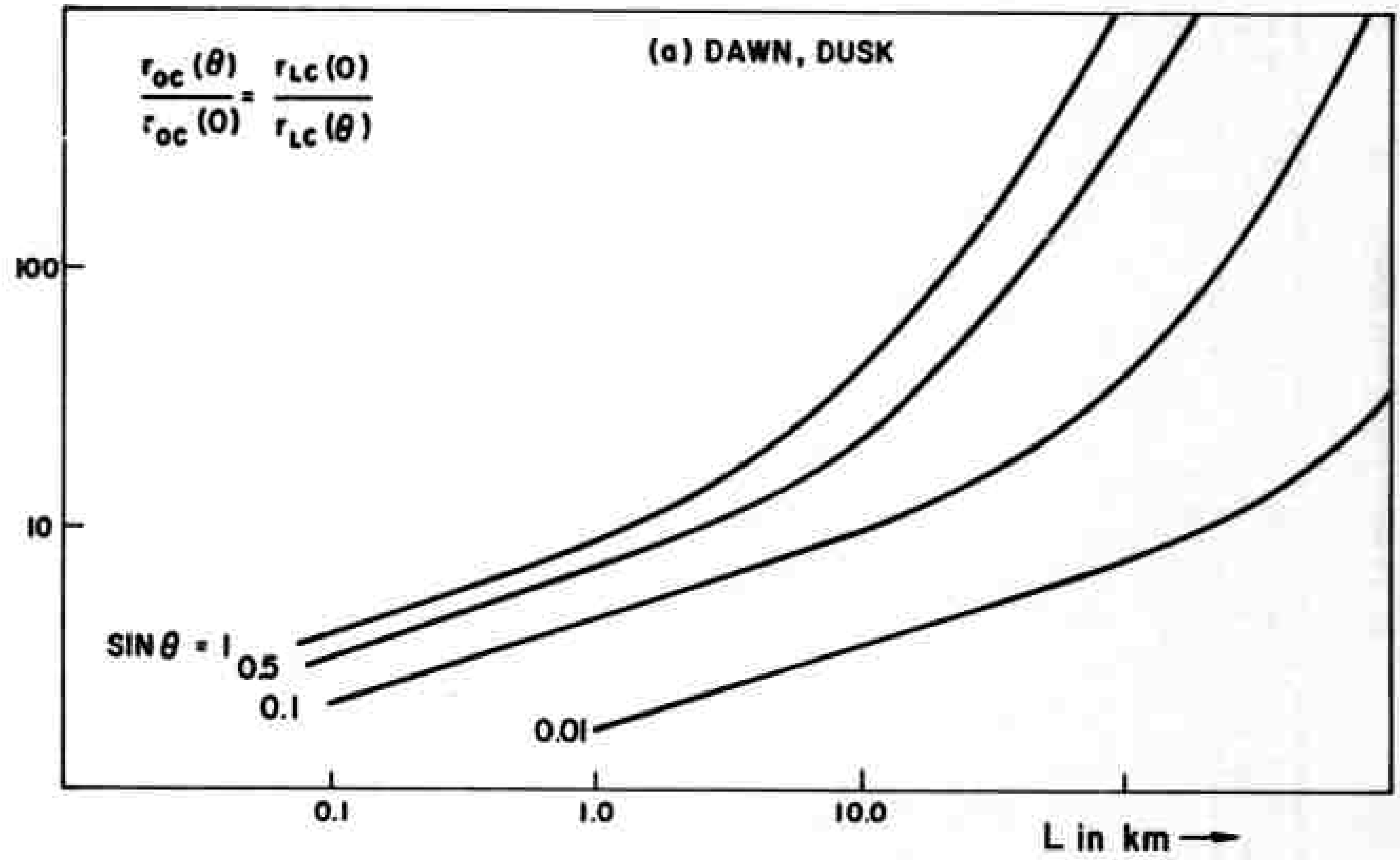

Figure 1(a). Average-Focal-Area Parameters for Diverse Angles of Elevation.

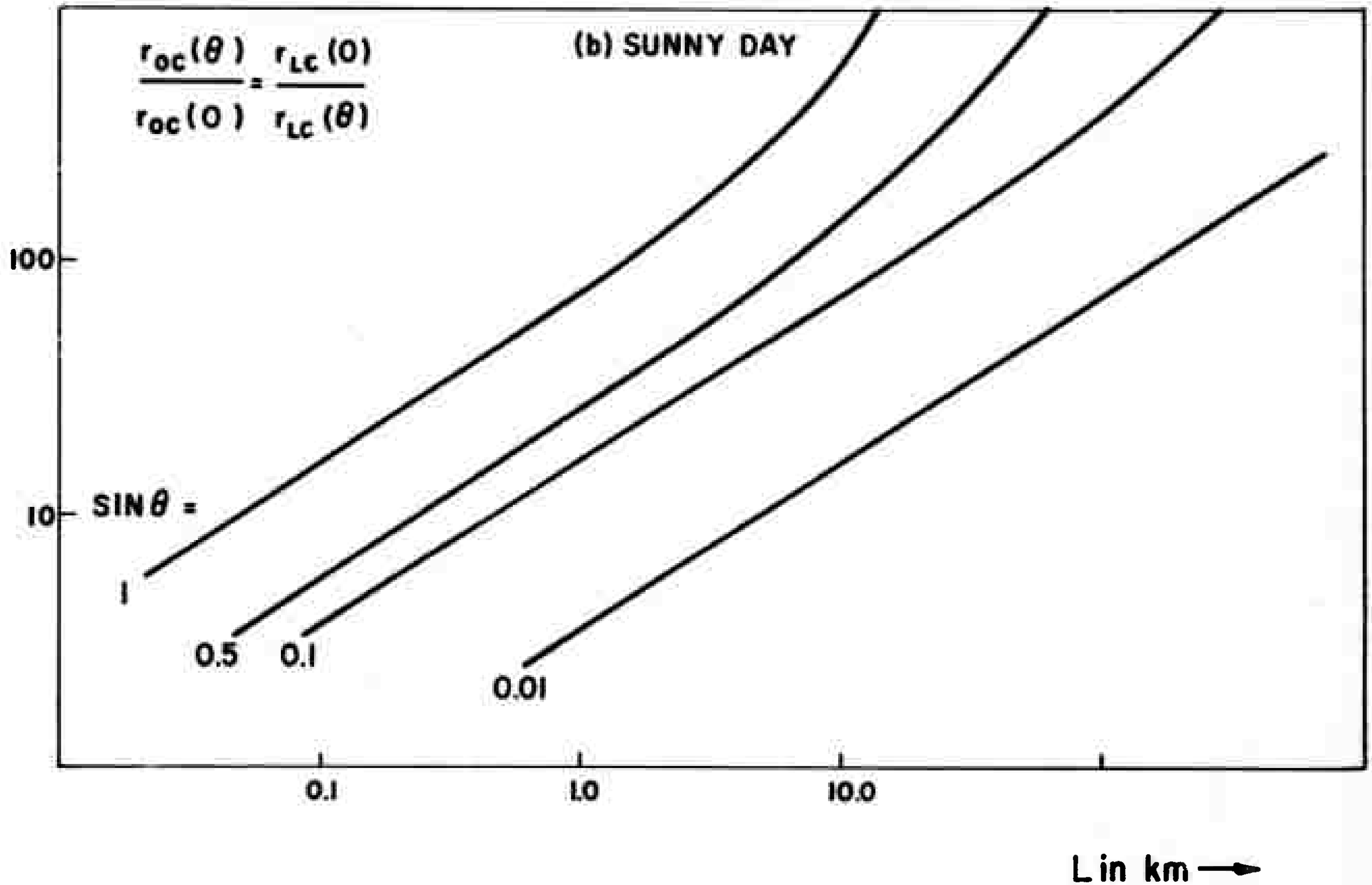

Figure 1(b). Average-Focal-Area Parameters for Diverse Angles of Elevation.

$$W(\omega;\rho) = \frac{15.7}{8\pi^{1/2}} \frac{\epsilon^2 L}{L_o \omega_2} \Gamma\left(\rho - \frac{1}{2}\right) U\left(\rho - \frac{1}{2}, \frac{1}{2}, \omega^2/\omega_2{}^2\right)$$

where $\omega_2 = 4v/L_o \sqrt{3}$, v is the root-mean-square velocity defining the gaussian velocity probability density (for zero mean), and Γ is the gamma function.

We have worked out a new approach to the statistics of I, the plane-wave irradiance. Previously, we were critical of previous selective-summation results (including our own) because these appeared incomplete. However, much of the formalism can be retained. By making a geometrical-optics approximation in the Green's function propagator, but retaining all diffraction effects, we obtain a non-linear set of coupled equations for the field E at the point of observation $\vec{r} = (\vec{\rho},L)$.

$$E \equiv E_o \exp\psi$$

$$\psi \equiv \chi + i\phi$$

$$\psi = \frac{ik}{8\pi^2}\int_o^L dz \int d^2K\ \delta\tilde{\epsilon}\ (\vec{K},z)\exp[-iK^2(L-z)/2k-i\vec{K}\cdot\vec{\xi}(z)]$$

$$\vec{\xi}(z) = \vec{\rho}(L)-(L-z)k^{-1}\vec{\nabla}_T\phi$$

Here, $\vec{\nabla}_T\phi$ is the transverse derivative of the (yet to be determined) phase function $\phi = \mathrm{Im}(\psi)$, and $\delta\tilde{\epsilon}\ (\vec{K},z)$ is a two-dimensional Fourier transform of $\delta\epsilon\ (\vec{\rho},z)$. The log-normal behavior of E is apparent; the problem is to obtain a saturation curve for the irradiance variance. If we ignore ray bending then $\xi = \vec{\rho}(L)$; in this case the Rytov approximation results. The next step is to include ray bending but this appears to be a difficult although promising task.

REFERENCE

1. J. Opt. Soc. Am. 61, 1646 (1971).